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DESCRIPTION

Transflective Liquid Crystal Displays

TECHNICAL FIELD

The invention relates to transflective liquid crystal displays, which rely for their operation on reflection of ambient light, and transmission of light from a backlight in the case of a low ambient light level.

BACKGROUND ART

European Patent Publication No. 0,840,160 A2 describes a Pancharatnam-type achromatic (ie. independent of frequency/colour) reflective liquid crystal display (LCD) using a twisted nematic liquid crystal (LC) layer as part of a switchable achromatic retarder.

British Patent Application No. 9806566.7 describes an improved retarder combination for an achromatic fixed retarder and twisted nematic (TN) LC used in high resolution thin film transistor (HR-TFT) displays, which reduces threshold voltage and chromaticity and improves contrast.

S. Fujiwara et al. "Proceedings of the Fourth International Display Workshops", Nagoya 1997, (IDW'97), p.879 describes a reflective LCD using an achromatic fixed retarder between a linear polariser and a twisted nematic LC. This is used in the HR-TFT LCD product produced by Sharp.

Solutions for converting linear polarised light to circular polarised light by a twisted nematic layer with respect to the LC parameters retardation, twist and alignment orientation can be found in Beynon et al., Proceedings of the International Display research Conference, 1997 L34.

US Patent No. 5,361,151 (Sonehara) describes a transflective LCD comprising a TN-LC layer, an internal or external semi-reflector, and chromatic retardation plates between the LC and the front and rear linear polariser.

US Patent No. 4,093,356 (J. E. Bigelow) describes a transflective liquid crystal display capable of presenting viewable indicia to an observer positioned at the front thereof,

which is responsive to either reflection of incident ambient light entering into the display from the front thereof, or transmission of light from a source behind the display, and which utilises a reflective display of the type having a nematic liquid crystal host-guest dichroic dye cell backed by a quarterwave plate and partially reflective, partially transmissive transflector member, in conjunction with a linear polariser and a second quarterwave plate arranged between the backlighting source and the partially transmissive member.

In such a guest-host cell, the dichroic dye is regarded as a guest in the liquid crystal, because the orientation of the dichroic dye molecules simply follows that of the LC molecules. The dye molecules are generally transparent when viewed along their long axes, and opaque (ie. they absorb visible light) when viewed perpendicular to their long axes, and are hence referred to as dichroic. Consequently, by applying a voltage to the LC cell, the degree of absorption in the cell can be controlled, and the cell is therefore sometimes referred to as operating in an absorption mode.

The rear quarterwave plate is used to compensate for the front quarterwave plate so that linear polarised light impinges on the guest-host liquid crystal (GH-LC).

US Patent No. 4,315,258 describes a visual display which has an increased readout capability due to its operation in a transflective mode. A source of ambient light and light for radiation through the display from the back together assure the increased readout capability. Previously, ambient light would degrade or wash-out the display making it nearly impossible for monitoring personnel to decipher alphanumeric or pictoral displays due to the decreased contrast. A pair of linear polarizers sandwich a twisted nematic liquid crystal and have their polarisation axes either parallel or mutually orthogonally disposed so that the crystal presents bright or dark areas in response to applied potentials. Because a partially transmitting mirror is interposed between the sandwiched liquid crystal and the radiating light source, the ambient light augments the radiated light to enhance the visual display.

It should be understood that, throughout this specification, references to retardation values should be understood as effective retardation values, taking into account the twist angle of the retarder. A twisted birefringent structure (such as a TNLC) has a retardation of thickness x birefringence for a particular wavelength. However, it effects a retardation which is lower or higher depending on the twist angle.

DISCLOSURE OF INVENTION

According to a first aspect of the invention there is provided a transflective liquid crystal display comprising a liquid crystal cell disposed between a front substrate and a rear substrate, a front polariser located in front of the front substrate and a rear polariser located behind the rear substrate, a front retarder located between the front substrate and the front polariser, a rear retarder located between the rear substrate and the rear polariser, and a light source located behind the rear polariser.

This allows the display to benefit from backlighting in low ambient light conditions and high contrast while still providing the benefits of an achromatic reflective display.

The front retarder may be an achromatic combination retarder.

The front retarder may comprise a front halfwave plate and a front quarterwave plate.

The front quarterwave plate may have a retardation of between 0nm and 250nm.

The front halfwave plate may have a retardation of between 200nm and 360nm.

The rear retarder may comprise a rear quarterwave plate.

The rear quarterwave plate may have a retardation of between 100nm and 180nm, and preferably of substantially 135 nm.

The rear substrate may be provided with a partially reflective and partially transmissive mirror.

Alternatively, the reflective layers can be thinned to an extent that it becomes partially transmissive to a predetermined value over the whole or part of the pixel electrode.

According to a second aspect of the invention, there is provided a transflective display comprising a liquid crystal divided into a plurality of pixels, addressing means for – addressing each pixel and switching each pixel between different states resulting in different levels of transmission of light through the display, a flashing backlight located behind the liquid crystal, and a partially reflective mirror located between the liquid crystal and the backlight for both reflecting ambient light back through the liquid crystal and allowing transmission of light from the backlight through the liquid crystal, wherein each pixel is provided with a light filter, and wherein the backlight comprises a plurality of sequentially flashing light sources.

In one embodiment, of the invention, each light filter is a colour light filter, and said sequentially flashing light sources are of different colours.

Said liquid crystal may be part of an active matrix display.

In one embodiment, the liquid crystal forms a Pi or optically compensated birefringent (OCB) cell.

In a further embodiment, each light source is a light emitting diode (LED).

Each colour filter may provide a varying level of absorption across its area.

Each colour filter may have a transparent region.

This provides the advantage of ensuring that a greater amount of light from each light source can pass through every colour filter.

In this case, said liquid crystal may be provided with a plurality of partially reflective electrodes each having a light transmissive area, and each transmissive area may be optically aligned with a transparent region of one of said colour filters.

molecules of which are oriented by the LC molecules in order to control the degree of absorption of the cell. The cell thus operates in an absorption mode. The GH-LC cell 16 is pixellated, with each pixel being controlled by a pair of electrodes (not shown) in known manner.

The display 2 is viewed from the position of the viewer 20. The light reaching the viewer 20 from the display is a combination of light from the light source 4 and (usually white) ambient light reflected by the partially reflective mirror 10. It is for this reason that the display is referred to as transflective, because it operates on the basis of both transmission and reflection.

The first embodiment of the invention, shown in Figure 2, is a transflective liquid crystal display 28 comprising a light source 30, a rear polariser 32, rear quarterwave plate 34, rear substrate 36, liquid crystal cell 38, front substrate 40, front quarterwave plate 42, front halfwave plate 44, and front polariser 46. The location of the viewer 20 is also indicated in Figure 2.

The arrangement of components of the display 28 from the front polariser 46 to the rear substrate 36 (inclusive) is known from the Fujiwara reference mentioned above, except that the rear substrate 36 of the display 28 is provided with a partially reflecting (and partially transmitting) mirror (not shown separately) instead of a fully reflecting mirror.

Figure 2 also indicates for each of the retarders 34, 42 and 44, the angle that the slow axis of the retarder makes with respect to the angle of the absorption axes of the two polarisers 32 and 46 (which are parallel, and defined as 0 degrees). These angles are -45°, -75° and -15° respectively. In addition, the angles at which the LC molecules are aligned by alignment layers (not shown) at the surfaces 48 and 50 of the LC cell 38 are also indicated in Figure 2. The surface director orientations (SDOs) are +50° and +140°, respectively. The term "surface director orientation" as used herein is defined as the orientation of the LC director at an alignment surface projected onto the plane of the alignment surface of the LC layer, so that the SDO is the orientation which the LC

director would have in the absence of any surface pretilt. Also, the SDO is equivalent to (SDO $\pm \pi$). The twist of the LC layer may be between 30° and 100°.

The two transparent parallel substrates 36 and 40 are each coated on the inside surfaces 52 and 54 with a patterned conductor/electrode (not shown) for addressing the LC cell 38, with the rear electrode being patterned and partially transparent and partially reflecting. The ratio of transmission to reflection of the rear conductor/electrode may be 1:1 or any other pre-determined value according to the designated purpose of the transflective display 28. The electrodes are coated with alignment means and hold the nematic LC cell 38 continuously switchable between an effective retardation in the reflecting bright state of 80nm to 200nm, and preferably 135nm, and in the dark state of 50nm to 0nm, and preferably close to 0nm. The nematic LC may be twisted by surface alignment and/or chiral doping.

The outer sides of the substrates 36 and 40 are clad by the transparent retardation films 34, 42 and 44. The front halfwave retarder 44 has a retardation $d\Delta n$ of substantially 270nm and the front quarterwave retarder 42 has a retardation $d\Delta n$ of substantially 133 nm, where d represents the thickness of the retarder film, and Δn represents the difference between the two refractive indices of the retarder film. The front quarterwave retarder 42 has its slow axis substantially parallel or normal to the bisetrix (ie. half the angle) of the (twist or) surface alignment directions of the nematic LC cell 38. (The angle -75° shown in Figure 2 is equivalent to +95° (ie. 75°+95°=180°), which lies half way between the SDOs + 50° and + 140° of the LC cell 38.). The two front retarders 42 and 44 form an achromatic combination retarder. The rear retarder 34 has a retardation $d\Delta n$ of substantially 133nm. The absorption or polarisation axis of the rear polariser 32 is at 45 degrees to the slow axis of the rear retardation film 34. The LC cell 38 may be MJ 96539 (Merck Japan), the retardation films 34, 42 and 44 of Nitto's NRZ range, and the polarisers 32 and 46 of Nitto's NPF range.

The bisetrix, or bisector, as used herein is the direction which bisects the smaller included angle between two directions. The bisetrix is also perpendicular to the optical axis of the device.

Figure 3 shows the results of computer modelling of the electrooptic response of the embodiment of Figure 2. The modelling was carried out assuming a standardised D65 light source for reflected and transmitted light in the wavelength range of 380 to 780 nm. The graph of Figure 3 shows voltage (applied to a pixel of the LC cell 38) against transmission and reflection in arbitrary units. The transmission results are shown by curve 56, and the reflection results by curve 58. For the reflection results a 0.1 micron aluminium mirror is assumed, and for the transmission results the mirror was removed.

When no voltage is applied, both the transmission and reflection are high, and the display thus operates in a "normally white mode". The rear quarterwave plate 34 is necessary in order to ensure that the transmission curve 56 is the correct way around. Without the quarterwave plate 34 the transmission curve 56 would be low at zero volts and high at 5 volts. It will be seen from Figure 3 that even at 4 or 5 volts there is still some residual transmission and reflection, which prevents the pixel from becoming fully dark. The embodiments discussed below seek to provide an improved contrast between the light and dark states.

Figure 3a shows the results of modelling the LC electrooptic response of the embodiment of Figure 2, but using crossed polarisers instead of parallel polarisers. That is, to produce the results of Figure 3a, the last two components (ie. the quarterwave plate 34 and polariser 32) are rotated through 90° compared to the arrangement shown in Figure 2. This results in a better (ie. darker) dark state for the transmission curve 56. The reflection curve is again labelled 58.

Figure 4 shows a second embodiment of the invention, which is a transflective display 60 providing reduced residual transmission in the dark state. Components which are the same as those of the first embodiment of Figure 2 are given the same reference numerals. The display of Figure 4 differs from that of Figure 2 in that the rear quarterwave plate 34 is replaced by a rear halfwave plate 62 and a rear quarterwave plate 64, which have slow axes at -15° and -75° respectively with respect to the absorption axes of the two polarisers 32 and 46. As shown by Figure 4, the components thus exhibit a degree of symmetry about the central LC cell 38. The combination of the

rear halfwave plate and rear quarterwave plate improves the achromaticity of the transmission mode.

The effective retardation of the nematic LC cell 38 is continuously switchable between about 135nm and 0nm in the same way as in the embodiment of Figure 2. The two front retarders 42 and 44 function together as an achromatic combination retarder, and the two rear retarders 62 and 64 also function together as an achromatic combination retarder. The retardation films can again be of Nitto's NRZ range.

Figure 5 shows the results of computer modelling of the electrooptic response of the embodiment of Figure 4. The transmission results are shown by curve 66, and the reflection results by curve 68. The assumptions mentioned above in relation to the graph of Figure 3 apply equally to the Figure 5. As shown by Figure 5, the embodiment of Figure 4 produces a slight reduction in the residual transmission (at around 4 to 5 volts) compared with the embodiment of Figure 2.

Figure 6 shows a third embodiment of the invention, which is a transflective display 70 providing both significantly reduced residual transmission and significantly reduced residual reflection. The components are essentially the same as those of the embodiment of Figure 4, and the same reference numerals are therefore used. However, the display 70 differs from that of Figure 4 in that the thickness of the front quarterwave plate (retarder) 42 is increased so that it has a retardation $d\Delta n$ of substantially 143 nm.

The front and rear quarterwave plates 42 and 64 have their slow axes substantially normal to the bisetrix of the surface director orientations of the nematic LC cell 38. The two front retarders 42 and 44, and the two rear retarders 62 and 64, each form an achromatic combination retarder. The front achromatic combination retarder is modified to compensate for the residual retardation of the LC cell at finite voltages. The retardation of quarterwave plate 42 is increased when the slow axis of each quarterwave plate is normal to the bisetrix of the SDOs of the nematic LC cell 38. Alternatively, if the slow axes of the quarterwave plates 42 and 64 are parallel to the bisetrix of the SDOs of the nematic LC cell 38, the retardation of quarterwave plate 42 needs to be decreased. The retardation films can again be of Nitto's NRZ range.

Figure 7 shows the results of computer modelling of the electrooptic response of the embodiment of Figure 6. The transmission results are shown by curve 72, and the reflection results by curve 74. The assumptions mentioned above in relation to the graph of Figure 3 apply equally to the Figure 7. As shown by Figure 7, the embodiment of Figure 6 produces a significant reduction in both the residual transmission and the residual reflection in the dark state (at around 4 to 5 volts) compared with the previous embodiments.

This improvement comes about because the increased thickness of the quarterwave plate 42 compensates for the residual retardation caused by the fact that those liquid crystal molecules in the LC cell 38 which lie close to the alignment layers (not shown separately) remain "fixed" in position when the LC cell 38 is switched by application of an external voltage.

Figure 7a uses the same reference numbers as Figure 7, and shows an improved (ie. darker) dark state for the transmission curve 56, achieved by rotating the last three components (ie. 32, 62 and 64) of Figure 6 through 90°, so that the polarisers 32 and 46 are crossed.

Figure 8 shows a fourth embodiment of the invention. The components of the transflective display 100 are essentially the same as those of the embodiments of Figures 4 and 6, and the same reference numerals are therefore used for components which are the same. However, the nematic LC cell 38 of Figures 4 and 6 is replaced by a hybrid aligned nematic (HAN) LC cell 102. The cell 102 used is LC MJ96539 produced by Merck, Japan and has antiparallel surface director orientation with surface pretilt of 2° and 88° and a retardation of substantially 137.5 nm. The orientations and retardations of the other components are given in Figure 8. The front substrate 40 also functions as a colour filter plate. The retardation of the front quarterwave plate 42 is changed to 151nm compared to 143nm for the TN cell.